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(54) **METHOD AND APPARATUS FOR SECURE DISTRIBUTION OF EMBEDDED FIRMWARE**

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G06F 21/00 (2013.01)

(52) **U.S. Cl.**

CPC **H04L 9/3263** (2013.01); **G06F 8/65** (2013.01); **G06F 21/00** (2013.01)

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CPC G06F 8/61; G06F 8/65; G06F 21/30;
H04L 9/3234; H04L 9/3294; H04L 9/3263

USPC 713/2, 175, 176, 191; 717/168, 174;
726/17, 21

See application file for complete search history.

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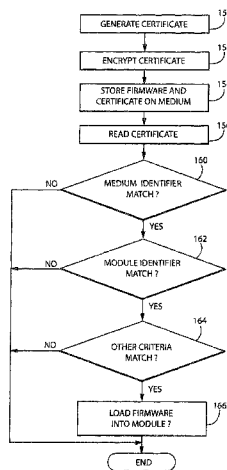
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(57) **ABSTRACT**

A method and apparatus to securely distribute embedded firmware to a module in an industrial control system is disclosed. A security certificate corresponding to the firmware is generated utilizing a proprietary algorithm. The certificate includes an identifier corresponding to the module on which the firmware is to be loaded and an identifier corresponding to a removable medium on which the firmware is distributed. The removable medium is inserted into the module in the industrial control system on which the firmware is to be loaded. The module reads the security certificate and verifies that the firmware is intended for the module and verifies that the security certificate includes the identifier for the removable medium which was inserted into the module. If the firmware is intended for the module and the security certificate includes the identifier for the removable medium, the module loads the firmware from the removable medium.

10 Claims, 4 Drawing Sheets



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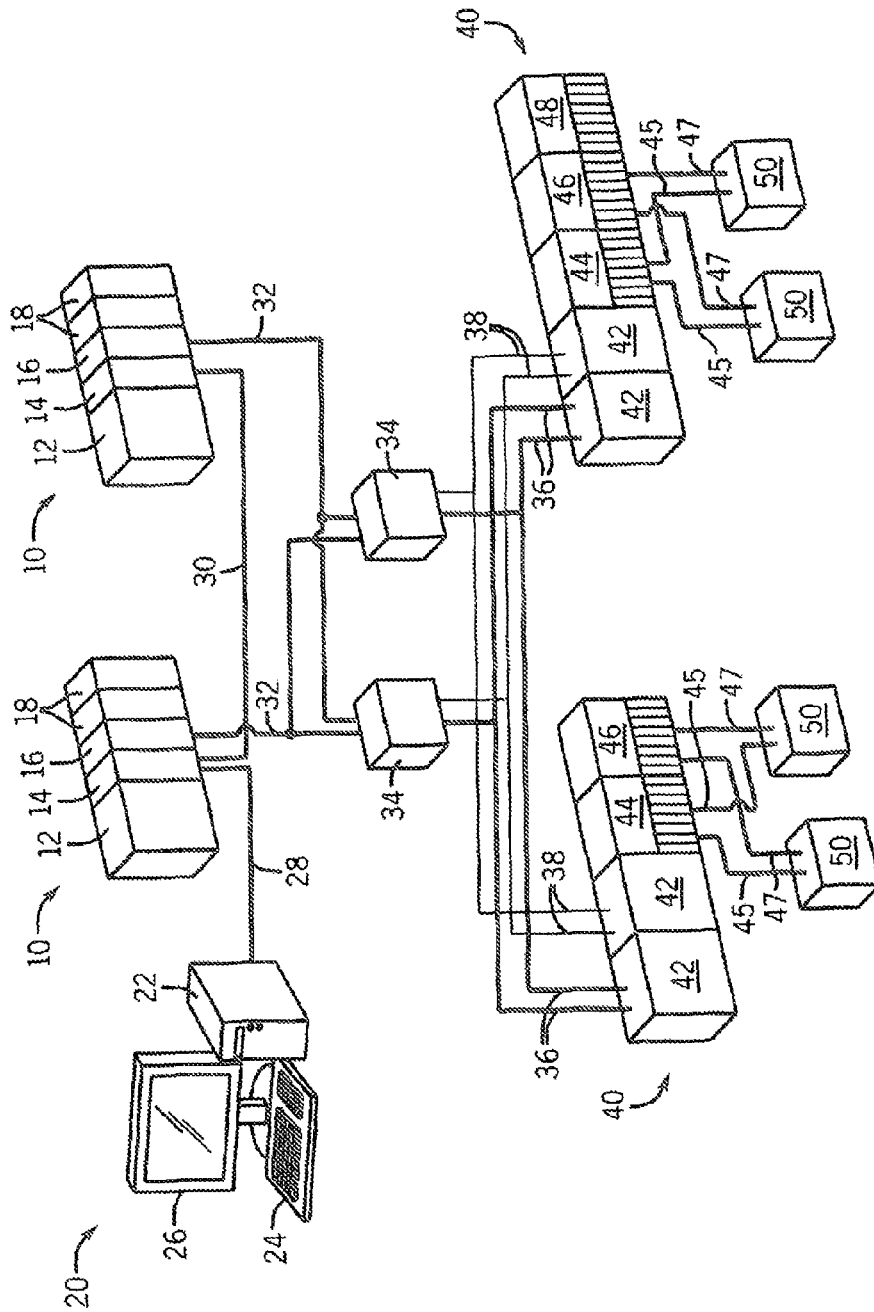


FIG. 1

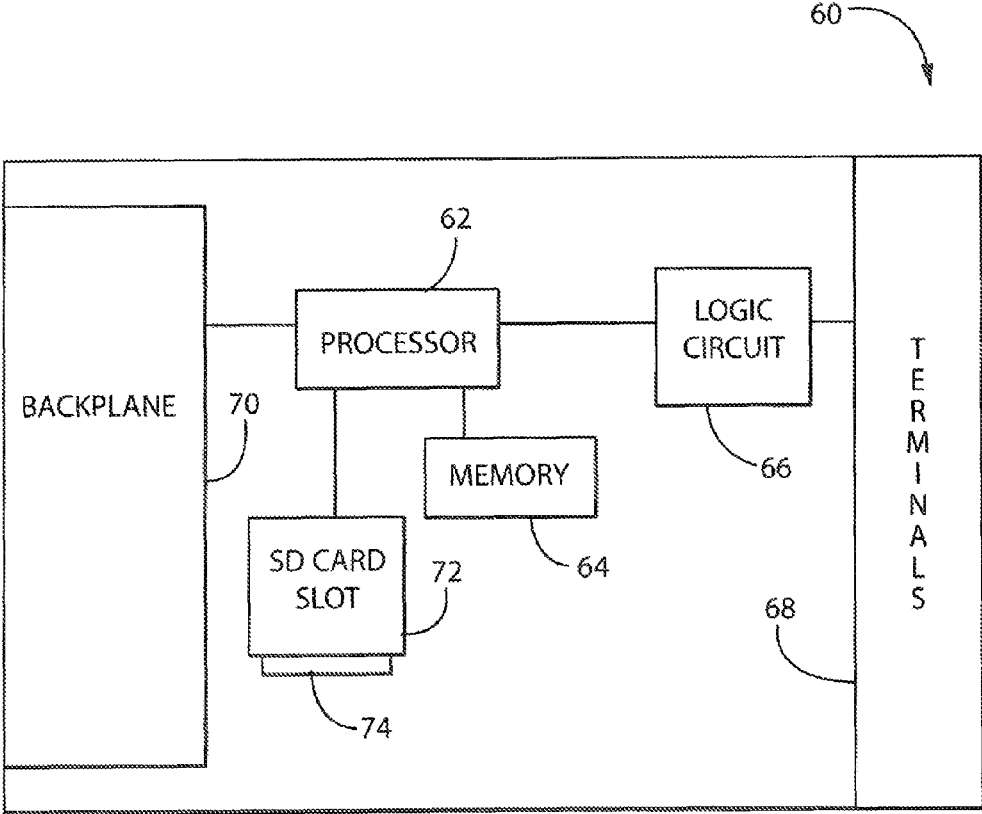


FIG. 2

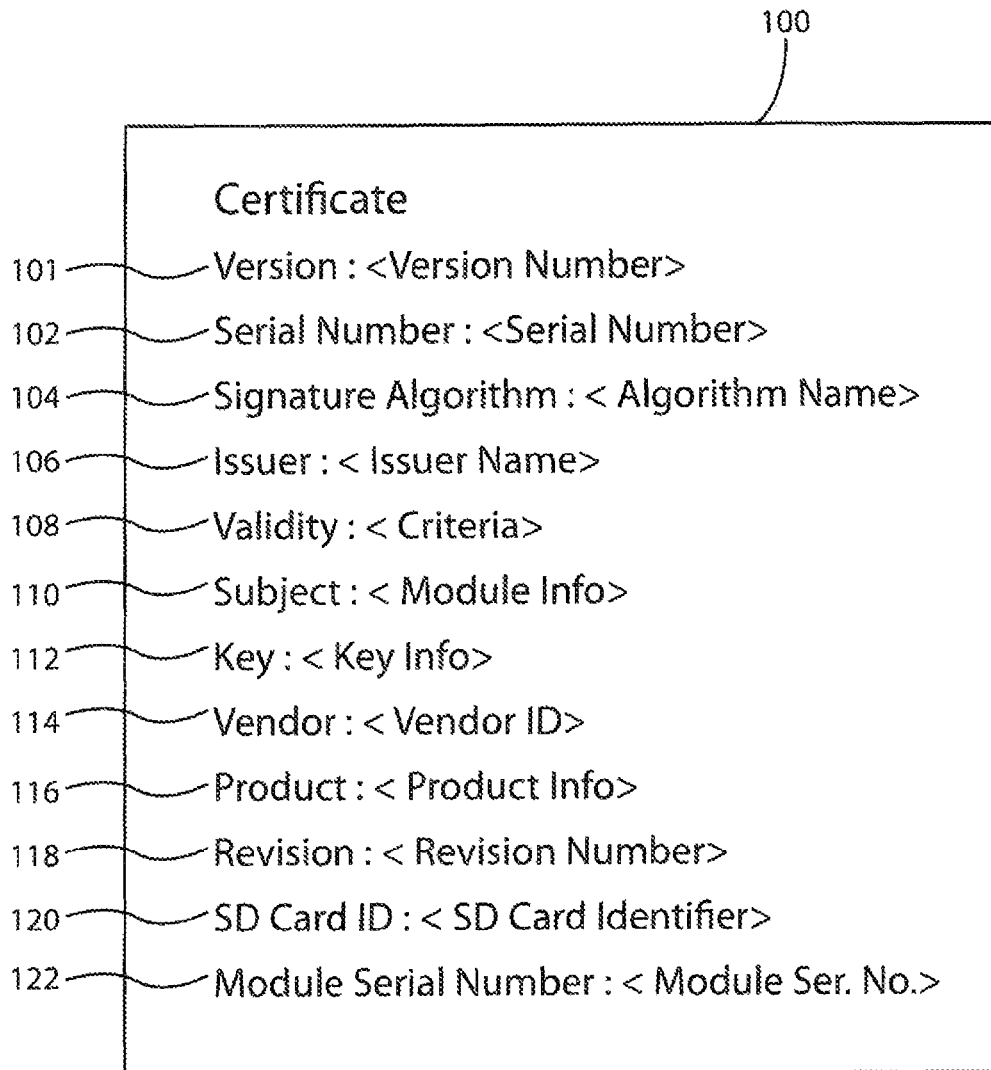


FIG. 3

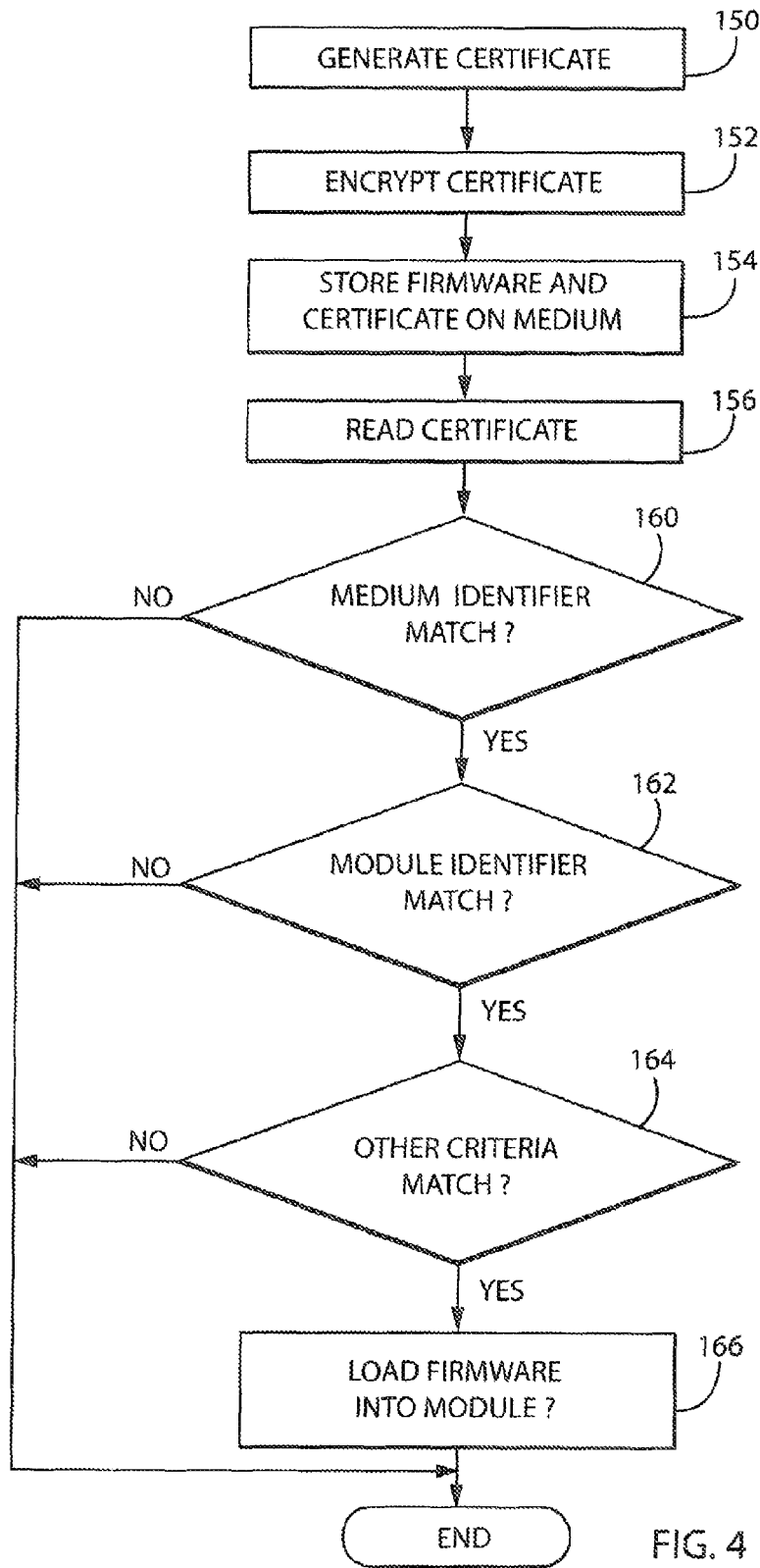


FIG. 4

METHOD AND APPARATUS FOR SECURE DISTRIBUTION OF EMBEDDED FIRMWARE

BACKGROUND OF THE INVENTION

The subject matter disclosed herein relates generally to a system and method for providing secure distribution of embedded firmware to modules in an industrial control system and more specifically, for utilizing a proprietary encryption certificate to distribute embedded firmware via a removable medium, such as a Secure Digital (SD) memory card.

An industrial control system typically includes at least one industrial controller configured to execute a control program and multiple modules distributed about the controlled machine or process. Industrial controllers are specialized computer systems used for the control of industrial processes or machinery, for example, in a factory environment. Generally, an industrial controller executes a stored control program that reads inputs from a variety of sensors associated with the controlled process and machine and, sensing the conditions of the process or machine and based on those inputs and a stored control program, calculates a set of outputs used to control actuators controlling the process or machine.

Industrial controllers differ from conventional computers in a number of ways. Physically, they are constructed to be substantially more robust against shock and damage and to better resist extreme environmental conditions than conventional computers. The processors and operating systems are optimized for real-time control and are programmed with languages designed to permit rapid development of control programs tailored to a constantly varying set of machine control or process control applications.

Generally, the industrial control systems have a highly modular architecture, for example, that allows different numbers and types of input and output modules to be used to connect the industrial controller to the process or machinery to be controlled. This modularity is facilitated through the use of special "control networks" suitable for highly reliable and available real-time communication. Such control networks (for example, ControlNet, EtherNet/IP) differ from standard communication networks (e.g. Ethernet) by guaranteeing maximum communication delays, by pre-scheduling the communication capacity of the network, and/or providing redundant communication capabilities for high-availability.

As part of their enhanced modularity, industrial control systems may employ modules that are configurable to perform different functions. A module may include, for example, sockets or slots configured to receive additional hardware such as an option card. Different option cards may be configured to execute different functions yet may be plugged into the same socket or slot. Optionally, a module may include all of the hardware components to perform several different functions. However, the hardware components may require a specific firmware and/or configuration in order to enable the hardware and the respective functions. Even if a module is not configurable, it likely includes a processor executing firmware to perform its intended function.

The increased reliance on firmware in the modules in an industrial control system presents certain challenges. On occasion, it may be necessary to provide new firmware to the module. For example, the firmware may receive an upgrade to improve performance and/or correct a problem in the module. Alternately, a customer may alter the configuration

of their control system and desire a different set of functions in the module be enabled. However, as is known in the art, many utilities exist to copy software files. Consequently, it is not desirable to simply transmit a new firmware file to a client for installation in the module. A client may, for example, purchase an upgrade for a single module and install the new software in multiple modules. Similarly, the potential exists for the software file to be loaded onto a computer or server, publicly accessible, for example, via the Internet. The firmware would then be available to all users of the module without purchase of an upgrade.

Thus, it would be desirable to provide an improved method for secure distribution of embedded firmware.

BRIEF DESCRIPTION OF THE INVENTION

The subject matter disclosed herein describes a method and apparatus to securely distribute embedded firmware to a module in an industrial control system. A security certificate corresponding to the firmware is generated utilizing a proprietary algorithm. The certificate includes an identifier corresponding to the module on which the firmware is to be loaded and an identifier corresponding to a removable medium, such as a SD memory card, on which the firmware is distributed. The removable medium is inserted into the module in the industrial control system on which the firmware is to be loaded. The module reads the security certificate and verifies that the firmware is intended for the module and verifies that the security certificate includes the identifier for the removable medium which was inserted into the module. If the firmware is intended for the module and the security certificate includes the identifier for the removable medium, the module loads the firmware from the removable medium.

According to one embodiment of the invention, an apparatus for providing firmware to a module in an industrial control system is disclosed. The apparatus includes a removable storage medium, a firmware file, and a certificate. The module includes a first identifier corresponding to the module, and the removable storage medium includes a second identifier corresponding to the removable storage medium. The firmware file is stored on the removable storage medium and defines, at least in part, operation of the module. The certificate is also stored on the removable storage medium and includes a copy of the first identifier corresponding to the module and a copy of the second identifier corresponding to the removable storage medium. The certificate is configured to be read by the module to permit the module to load the firmware file to the module when the copy of the first identifier in the certificate matches the first identifier included on the module and the copy of the second identifier in the certificate matches the second identifier on the removable storage medium.

According to another embodiment of the invention, a method of providing secure distribution of embedded firmware for a module in an industrial control system is disclosed. A removable storage medium is inserted into a receptacle on the module, and a certificate stored on the removable storage medium is read with the module. The module verifies that the certificate includes a copy of a first identifier corresponding to the module and a copy of a second identifier corresponding to the removable storage medium. A firmware file is loaded from the removable storage medium to the module when the copy of the first identifier in the certificate matches the first identifier

included on the module and the copy of the second identifier in the certificate matches the second identifier on the removable storage medium.

These and other advantages and features of the invention will become apparent to those skilled in the art from the detailed description and the accompanying drawings. It should be understood, however, that the detailed description and accompanying drawings, while indicating preferred embodiments of the present invention, are given by way of illustration and not of limitation. Many changes and modifications may be made within the scope of the present invention without departing from the spirit thereof, and the invention includes all such modifications.

BRIEF DESCRIPTION OF THE DRAWINGS

Various exemplary embodiments of the subject matter disclosed herein are illustrated in the accompanying drawings in which like reference numerals represent like parts throughout, and in which:

FIG. 1 is a schematic representation of an exemplary industrial control system incorporating modules which may receive embedded firmware according to one embodiment of the invention;

FIG. 2 is a block diagram representation of an exemplary module from the industrial control system of FIG. 1;

FIG. 3 is a block diagram representation of an exemplary certificate according to one embodiment of the invention; and

FIG. 4 is a flowchart illustrating the steps in a load process to install new firmware in a module according to one embodiment of the invention.

In describing the various embodiments of the invention which are illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, it is not intended that the invention be limited to the specific terms so selected and it is understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose. For example, the word "connected," "attached," or terms similar thereto are often used. They are not limited to direct connection but include connection through other elements where such connection is recognized as being equivalent by those skilled in the art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Turning initially to FIG. 1, an exemplary industrial control network includes a pair of industrial controllers 10. As illustrated, the industrial controller 10 is modular and may be made up of numerous different modules connected together in a rack or mounted to a rail. Additional modules may be added or existing modules removed and the industrial controller 10 reconfigured to accommodate the new configuration. Optionally, the industrial controller 10 may have a predetermined and fixed configuration. Each of the illustrated industrial controllers 10 includes a power supply module 12, processor module 14, and network module 16. Each industrial controller 10 is further shown with two additional modules 18 that may be selected according to the application requirements and may be, for example, analog or digital input or output modules.

One or more operator interfaces 20 may be connected to the industrial control network. Each operator interface 20 may include a processing device 22, input device 24, including, but not limited to, a keyboard, touchpad, mouse, trackball, or touch screen, and a display device 26. It is contemplated

that each component of the operator interface may be incorporated into a single unit, such as an industrial computer, laptop, or tablet computer. It is further contemplated that multiple display devices 26 and/or multiple input devices 24 may be distributed about the controlled machine or process and connected to one or more processing devices 22. The operator interface 20 may be used to display operating parameters and/or conditions of the controlled machine or process, receive commands from the operator, or change and/or load a control program or configuration parameters. An interface cable 28 connects the operator interface 20 to one of the industrial controllers 10.

The industrial controllers 10 are connected to other devices by one or more networks according to the application requirements. As illustrated, an interface cable 30 directly connects each of the processor modules 14. A redundant network topology is established by connecting the network interface module 16 of both industrial controllers 10 to each of a pair of switches 34 by a network cable 32. Each switch 34 is connected to one of a pair of remote racks 40 by a suitable network cable 36, 38. It is contemplated that the interface cable 30 or any of the network cables 32, 36, 38 may be a custom cable configured to communicate via a proprietary interface or may be any standard industrial network, including, but not limited to, Ethernet/IP, DeviceNet, or ControlNet. Each network module 16 and switch 34 is configured to communicate according to the protocol of the network to which it is connected and may be further configured to translate messages between two different network protocols.

Each remote rack 40 may be positioned at varying positions about the controlled machine or process. As illustrated, each remote rack 40 is modular and may be made up of numerous different modules connected together in a rack or mounted to a rail. Additional modules may be added or existing modules removed and the remote rack 40 reconfigured to accommodate the new configuration. Optionally, the remote rack 40 may have a predetermined and fixed configuration. As illustrated, each remote rack 40 includes a pair of network modules 42, each network module 42 connected to one of the redundant networks, an input module 44, and an output module 46. Each of the input modules 44 is configured to receive input signals 45 from controlled devices 50, and each of the output modules 46 is configured to provide output signals 47 to the controlled devices 50. Optionally, still other modules 48 may be included in the remote rack 40. It is understood that the industrial control network, industrial controller 10, and remote racks 40 may take numerous other forms and configurations without deviating from the scope of the invention.

Turning next to FIG. 2, an exemplary module 60 from the industrial control network of FIG. 1 is illustrated. The exemplary module 60 is not intended to be limiting and may be, for example, an input, or output module connected in a rack from one of the industrial controllers 10 or in one of the remote racks 40. Optionally, the exemplary module 60 may be a special function module such as a processor module 14 or network interface module 16. According to still other embodiments, the exemplary module 60 may perform other functions. The exemplary module 60 is intended to illustrate components common in any of the modules configured to receive embedded firmware via the secure distribution method disclosed herein. The exemplary module 60 includes a processor 62 and a memory device 64. The processor 62 is configured to execute instructions and to access or store operating data and/or configuration parameters stored in the memory device 64. The processor 62 may be any suitable

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processor according to the node requirements. It is contemplated that the processor **62** may include a single processing device or multiple processing devices executing in parallel and may be implemented in separate electronic devices or incorporated on a single electronic device, such as a field programmable gate array (FPGA) or application specific integrated circuit (ASIC). Similarly, the memory device **64** may be a single device, multiple devices or may be incorporated in part or in whole within the FPGA or ASIC. The memory device **64** may include volatile memory, nonvolatile memory, or a combination thereof. The module **60** may be configured to communicate with other modules mounted in the same rack or contained within a single housing via a backplane and a corresponding backplane connector **70**. Optionally, the module may communicate with other modules via a network interface and associated network media according to a corresponding network protocol. The module **60** includes terminals **68** configured to be connected to external devices to receive input signals, transmit output signals, or a combination thereof. An additional logic circuit **66** may be included between the processor **62** and the terminals **68** to convert the input and output signals between the proper signals for communication with external devices and the proper signals for communication with the processor **62**. It is contemplated that the logic circuit **66** may be implanted via separate electronic devices, incorporated into a single device, such as a FPGA or ASIC, or a combination thereof.

The exemplary module **60** also includes a removable storage device. According to the illustrated embodiment, the module **60** includes a Secure Digital (SD) memory card slot **72**. An SD memory card **74** may be inserted into and removed from the SD memory card slot **72**. Optionally, the module **60** may include an integrated circuit (IC) socket configured, for example, to receive a plastic leaded chip earner (PLCC) package IC chip, and a corresponding PLCC IC chip may be inserted to and removed from the socket. It is contemplated that still other configurations of removable storage devices and corresponding receptacles may be utilized without deviating from the scope of the invention.

Each module **60** includes a program stored in the memory device **64** for execution by the processor **62**. The program is configured to control operation of the module and is retained in non-volatile memory through a power cycle. The program is also referred to herein as firmware. Initially, the program may be loaded into the memory device **64** when the module **60** is manufactured. The firmware supports, for example, the boot functions, runtime control functions, interrupt handling, background functions, communication functions, and other functions of the module **60** according to the module specifications. It is contemplated that the firmware may include either a single program or multiple programs.

Newer revisions of the same firmware and/or different firmware may be loaded into the module **60**. However, it is desirable to prevent unauthorized firmware from being loaded into the module **60**. Thus, the firmware may include a certificate **100** used to authenticate the firmware. With reference to Fig. 3, the certificate **100** may include, but is not limited to, fields identifying a version **101** of the firmware, a serial number **102** of the firmware, a signature algorithm **104** used to generate the certificate, the issuer **106** of the firmware, validity criteria **108**, module information **110**, a key **112** used to encrypt and/or decrypt the certificate, vendor identification **114**, product information **116**, a revision number **118**, a SD card identifier **120**, and/or a module serial number **122** for a particular instance of a module **60**. It is contemplated that the certificate **100** may include some

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or all of the fields illustrated or further include still additional fields without deviating from the scope of the invention. The certificate **100** may be encrypted according to a proprietary process by the vendor of the firmware and/or the vendor of the module prior to release to the module **60**. The module **60** is configured to identify and decrypt the certificate to confirm that the firmware is valid prior to loading the firmware on to the module **60**.

Referring next to FIG. 4, when new firmware is generated for a module **60**, the firmware vendor also generates a certificate **100** associated with the firmware, as shown in step **150**. The firmware vendor populates as many of the fields for the certificate **100** as appropriate for the firmware. At least one of the fields in the certificate **100** is an identifier of the module **60** on which the firmware is to be loaded. This field may be, for example, the subject field **110** shown in FIG. 3. Another of the fields includes an identifier corresponding to the removable storage medium **74** on which the firmware is to be stored. An SD memory card **74**, for example, includes an identifier written in a read-only segment of the SD memory card **74** by the memory card manufacturer. The SD card identifier may be loaded into the SD card ID field **120** shown in FIG. 3. The certificate **100** is then encrypted by a proprietary encryption algorithm, as shown in step **152**. According to one embodiment of the invention, the certificate is generated and encrypted according to the methods disclosed in U.S. Pat. No. 8,484,474, entitled Methods for Firmware Signature. The '474 patent and the present application are commonly owned by Rockwell Automation Technologies, and the contents of the '474 patent are hereby incorporated by reference in their entirety.

According to one aspect of the invention, it may be desirable to generate firmware that has a limited duration of time during which the firmware may be executed. For example, a demo version of firmware may be provided to a customer to try a new feature of the firmware. The vendor may allow the customer to execute the demo version for a short period, such as a one month trial. As another example, a vendor may issue a pre-release version of software for evaluation or use by select customers in advance of a general release. The firmware may be limited to use until the general release date at which time the general release of the firmware would be installed. The validity field **108** may include an initial date and a final date on which the firmware is valid. These dates may be utilized by the module **60** such that the firmware is only executable between these dates.

According to another aspect of the invention, it may be desirable to generate firmware for a specific instance of a module **60**. For example, a customer may have ordered a module **60** for which a serial number has been assigned. The customer initially ordered a base version of the firmware and wishes to add additional features to the module **60**. The vendor may include a firmware file which includes either configuration parameters for the new features and/or new control software to execute the new features. The module serial number field **122** may include the serial number for the module **60** such that the firmware may only be installed on the particular module **60**. Optionally, multiple serial numbers may be included in the module serial number field **122**. If the customer has multiple instances of the module **60** to upgrade, a single SD memory card **74** may be sent out and each of the instances of the module **60** may then be upgraded.

With reference to step **154** of FIG. 4, after the firmware file and corresponding certificate **100** have been generated and/or encrypted, the firmware file and certificate **100** are stored on the removable medium corresponding to the

identifier in the SD card ID field **120** included in the certificate. Thus, the firmware file and certificate **100** are associated with a particular SD memory card **74**. The SD memory card **74** may then be shipped to the customer or to a field installation to update the firmware on a module **60** in the industrial control system.

The module **60** is configured to verify the certificate **100** prior to loading the firmware file onto the module **60**. Referring still to FIG. **4**, the module **60** is configured to read the certificate **100** from the SD memory card **74**, as shown in step **156**. The module **60** includes a proprietary decryption algorithm to decode and read the fields from the certificate **100**. According to one embodiment of the invention, the module decrypts the certificate according to the methods disclosed in U.S. Pat. No. 8,484,474, entitled Methods for Firmware Signature. At step **160**, the module **60** reads the SD card ID field **120** from the certificate **100** and also reads the read-only segment of memory on the SD memory card **74** to retrieve the identifier corresponding to the SD memory card **74**. If the copy of the identifier in the certificate **100** does not match the identifier on the SD memory card **74**, the certificate may have become corrupted or the file may have been copied from the original medium to another medium. As a result, the module **60** ends the load process when the copy of the SD memory card identifier does not match the SD memory card identifier.

If the copy of the SD memory card identifier in the certificate **100** matches the identifier on the SD memory card **74**, the module **60** continues with the load process. At step **162**, the module **60** reads the subject field **110** from the certificate **100** and compares the copy of the module identifier to the corresponding identifier stored in the module **60**. The module identifier may identify the module **60** more generally including, for example, a type of module **60** and/or a product code indicating features available on the module **60**. If the copy of the identifier in the certificate **100** does not match the identifier in the module **60**, the certificate may have become corrupted or the file is not intended for that particular module **60**. As a result, the module **60** ends the load process when the copy of the module identifier does not match the module identifier.

If the copy of the module identifier in the certificate **100** matched the identifier in the module **60**, the module **60** continues with the load process. At step **164**, the module **60** determines whether any further criteria in the certificate **100** are required to match prior to loading and/or running the firmware. For example, if the module serial number field **122** is populated, identifying a specific module, or modules, the module **60** checks whether the serial number, or one of the serial numbers, matches the serial number of the module **60**. Similarly, if the validity field **108** includes other criteria, such as a range of dates for which the firmware is valid, the module **60** copies the range of dates into the module **60**. Using an internal clock within the module **60**, the module **60** is then permitted to execute the firmware when the clock indicates that the date is within range of dates provided in the certificate **100**. If all of the criteria match, the module **60** loads the firmware from the SD memory card **74** into the module, as shown in step **166**.

It should be understood that the invention is not limited in its application to the details of construction and arrangements of the components set forth herein. The invention is capable of other embodiments and of being practiced or carried out in various ways. Variations and modifications of the foregoing are within the scope of the present invention. It also being understood that the invention disclosed and defined herein extends to all alternative combinations of two

or more of the individual features mentioned or evident from the text and/or drawings. All of these different combinations constitute various alternative aspects of the present invention. The embodiments described herein explain the best modes known for practicing the invention and will enable others skilled in the art to utilize the invention.

We claim:

1. An apparatus for providing firmware to a module in an industrial control system, wherein the module includes a first identifier corresponding to the module, the apparatus comprising:

a removable storage medium for distributing the firmware, wherein the removable storage medium includes a second identifier corresponding to the removable storage medium and wherein the second identifier is written in a read-only segment on the removable storage medium by a manufacturer of the removable storage medium;

a firmware file stored on the removable storage medium, wherein the firmware file is executable by the module to control, at least in part, operation of the module when loaded on the module; and

a certificate used to authenticate the firmware file and stored on the removable storage medium, wherein:

the certificate includes a copy of the first identifier corresponding to the module and a copy of the second identifier corresponding to the removable storage medium, and

the certificate is configured to be read by the module to permit the module to load the firmware file to the module when the copy of the first identifier in the certificate matches the first identifier included on the module and the copy of the second identifier in the certificate matches the second identifier on the removable storage medium.

2. The apparatus of claim **1** wherein the removable storage medium is a secure digital (SD) memory card.

3. The apparatus of claim **1** wherein the certificate includes a predefined duration during which the firmware file is valid.

4. The apparatus of claim **1** wherein the certificate includes a copy of a serial number corresponding to a particular instance of the module and wherein the certificate is further configured to permit the module to load the firmware file when the copy of the serial number in the certificate matches the serial number of the module.

5. The apparatus of claim **1** wherein the firmware file is a configuration file to enable at least one additional feature of an application program configured to execute on the module.

6. The apparatus of claim **1** wherein the firmware file is a new revision of an existing firmware file loaded on the module.

7. A method of providing secure distribution of embedded firmware for a module in an industrial control system, the method comprising the steps of:

inserting a removable storage medium into a receptacle on the module;

reading a certificate stored on the removable storage medium to authenticate the firmware file with the module;

verifying on the module that the certificate includes a copy of a first identifier corresponding to the module and a copy of a second identifier corresponding to the removable storage medium, wherein the second identifier is written in a read-only segment on the removable storage medium by a manufacturer of the removable storage medium; and

loading a firmware file from the removable storage medium to the module when the copy of the first identifier in the certificate matches the first identifier included on the module and the copy of the second identifier in the certificate matches the second identifier on the removable storage medium, wherein the firmware file is executable by the module to control, at least in part, operation of the module when loaded on the module. 5

8. The method of claim 7 wherein the removable storage medium is a secure digital (SD) memory card. 10

9. The method of claim 7 wherein the certificate includes a. predefined duration during which the firmware file is valid, further comprising the step of loading the predefined duration from the removable storage medium to the module. 15

10. The method of claim 7 wherein the certificate includes a copy of a serial number corresponding to a particular instance of the module and wherein the module is further permitted to load the firmware file when the copy of the serial number in the certificate matches the serial number of the module. 20

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